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STATISTICAL EVALUATION OF 80 kHz SHALLOW-WATER SEAFLOOR REVERBERATION

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Statistical evaluation of 80 kHz shallow-water seafloor reverberation

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Statistical evaluation of 80 kHz shallow-water seafloor reverberation

A. P. Lyons, D. A. Abraham, T. Akal
and P. Guerrini

Executive Summary: Current mine hunting systems employ high frequency sonars to detect in volume and ground mines and to distinguish them from non-mine objects. The principal hindrance to the detection of sonar returns from ground or buried mines is the reverberation or backscatter from the sea bed. Detection algorithms traditionally assume that the reverberation amplitude follows a Rayleigh statistical distribution. However, non-Rayleigh reverberation may arise when the range-bearing resolution cell size is small (as will occur with parametric or wide aperture arrays, synthetic aperture sonar and wide bandwidth transmit waveforms) or if the sea bottom is inhomogeneous in such a way that it is composed of patches of different bottom materials. Non-Rayleigh reverberation affects the design and performance of mine detection algorithms.

This report examines high frequency (80 kHz) bottom reverberation from multiple sites around Sardinia and Sicily, including sites with *Posidonia Oceanica* sea grass, live shellfish, mud or sand. The average reverberation power or backscatter strength was observed to be high for the shellfish and posidonia sites and less so for the mud and sand sites. The amplitude statistics were observed to be non-Rayleigh for high grazing angles (i.e., the sonar was pointed more directly at the sea floor); however the K and Rayleigh mixture probability distributions fitted well. At lower grazing angles, the reverberation amplitude statistics were well described by the Rayleigh distribution.

It should be noted that these results are dependent upon the particular sonar used to obtain the experimental data. Nevertheless, they indicate that the reverberation received by a higher resolution sonar would be more non-Rayleigh than the data examined in this report.

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Statistical evaluation of 80 kHz shallow-water seafloor reverberation

A. P. Lyons, D. A. Abraham, T. Akal
and P. Guerrini

Abstract: Knowledge of the background reverberation environment is a prerequisite for the design of any target detection scheme. While the problem of understanding and predicting high-frequency background reverberation level or mean energy scattered per unit area of the sea bed has received considerable attention, studies of high frequency reverberation amplitude statistics are relatively scarce. Of these studies, many have dealt with scattering from more or less homogeneous seafloors in terms of bottom type whereas most shallow water areas will not be homogeneous but will have patchiness in space and time which will have a strong influence on reverberation amplitude statistics.

In this work a comparison is presented between 80 kHz reverberation statistics obtained at shallow water sites around Sardinia and Sicily. The data include measurements from several distinct bottom provinces, including sites with *Posidonia Oceanica* sea grass and sites covered with live shellfish. Results of the analysis are cast both in terms of mean power level or backscattering coefficient as well as of the amplitude statistics. The reverberation statistics did not always exhibit a Rayleigh probability distribution function (PDF), but exhibited statistical distributions with heavier tails. Several more appropriate models of reverberation PDF were examined in order to better describe the measured amplitude distributions. The Rayleigh mixture and the K models were found to be the most robust in describing the observed data.

Keywords: non-Rayleigh reverberation ◦ seafloor scatter ◦ high frequency ◦ posidonia

Contents

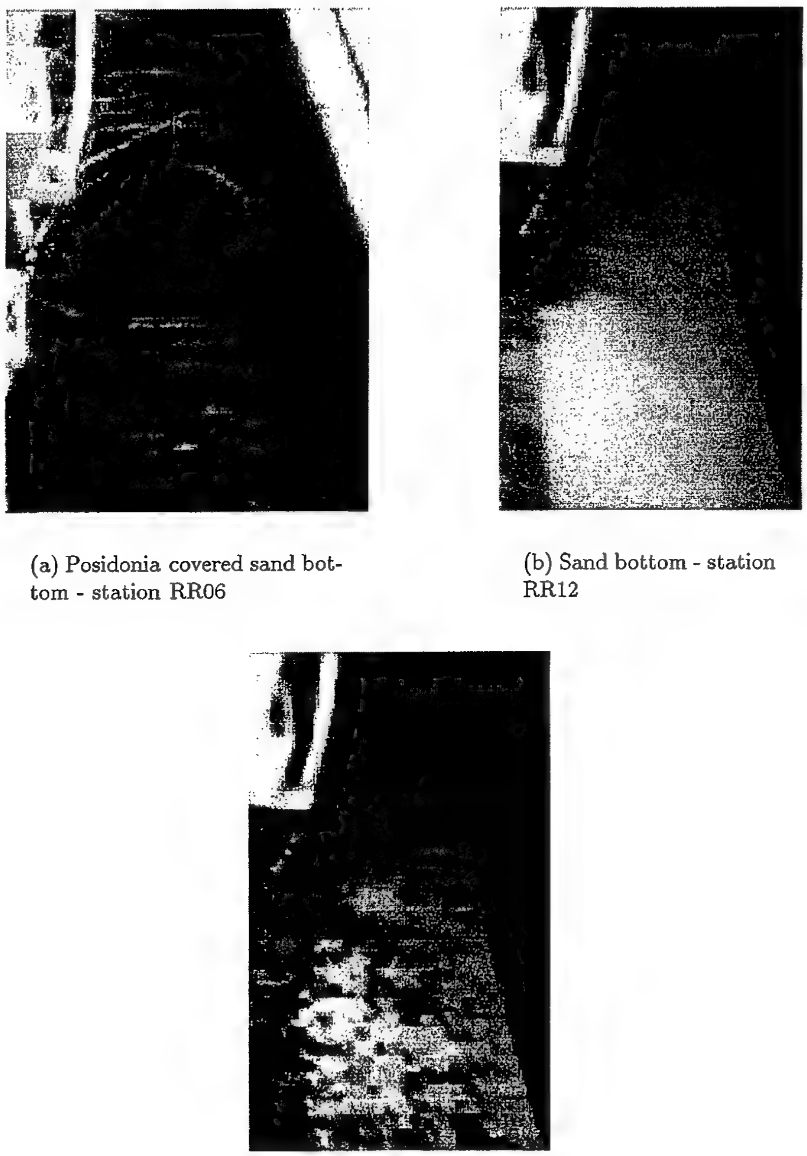
1
Introduction

The acoustic detection and identification of objects on the seafloor is hindered by seafloor reverberation. Although the problem of understanding and predicting high-frequency background reverberation level or mean energy scattered per unit area of the sea bed has received considerable attention, studies of high frequency reverberation statistics are relatively scarce. Of these studies, many have dealt with scattering from more or less homogeneous seafloors in terms of bottom type or scatterer distribution [1, 2, 3]. Most shallow water areas, however, will not be homogeneous but will have patchiness in space and time, which may be a result of the local biology. Shellfish are an example of spatial inhomogeneity which often do not exist uniformly on the seabed but are distributed in clumps of varying density with distance scales of decimeters to meters. The motion of seagrass in swell or currents causes a constantly changing number of scattering sites which can be thought of as time varying patchiness on scales of a few seconds.

Clutter is the acoustic expression of the non-uniformity of these types of seafloor environments. When the effective number of scatterers in the resolution cell of a sonar is large enough, the amplitude distribution is expected to be Rayleigh as the central limit theorem holds resulting in Gaussian reverberation. The changes in density of scatterers commonly found in shallow water suggests that this model might not always be appropriate especially when the area insonified by the transmit and receive beam patterns is not large enough to encompass enough of the patches of differing scatterer density. The non-Rayleigh nature of the amplitude statistics for seafloor scattering has been noted before, [2, 3], and attempts have been made to fit various models to the observed amplitude distributions including Weibull, log-normal, and Gaussian probability distributions functions (PDFs). Several distributional models with a somewhat more physical basis than the log-normal or the Weibull can be described as being the product of two components. These include the K distribution [4, 5], and models developed by McDaniel [6] and Crowther [7]. While these models have been successful in describing various characteristics of the amplitude PDFs, such as the beamwidth dependence, difficulty in parameter estimation and lack of generality could be considered drawbacks. Another alternative PDF model is one composed of a mixture of Rayleigh distributions [8].

This paper presents a statistical analysis of 80 kHz acoustic data collected at 14 shallow water (17 - 90 m depth) sites around Sardinia and Sicily. The study sites

consisted of areas with coarse sediments, fine sediments and also areas with a variety of more inhomogeneous (i.e., patchy) bottom types, including sites with *Posidonia Oceanica* sea grass and sites covered with live shellfish. Examples of three of the types of seafloor studied are shown in the video stills seen in Fig. 1. The diversity of sites studied allowed an excellent opportunity to examine the statistics of reverberation from a wide variety of seafloor environments to determine more appropriate statistical models for amplitude PDFs than the Rayleigh. Results of statistical analysis are cast in terms of mean power level or backscattering coefficient as well as analysis of the amplitude statistics. Rayleigh, Weibull, K, and 3-component Rayleigh mixture probability distribution functions are compared to measured data and a non-parametric test is used to describe the goodness of fit between modeled and measured amplitude distributions. The relationship between the mean scattered level and bottom type is also examined.



(a) Posidonia covered sand bottom - station RR06

(b) Sand bottom - station RR12

(c) Shell covered sand bottom - station RR13

Figure 1 *Examples of the diversity of sand seafloors: the potential for inhomogeneity is observed in the shell and posidonia examples.*

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Experimental measurements and data analysis

The 80 kHz acoustic system used in this study has been fully calibrated against reference hydrophones at the SACLANT Undersea Research Centre to quantify source level and beam pattern. The configuration of the acoustic system used in this study is displayed in Fig. 2 for two different tilt angles of the transducer beam axis. The dark patches in this figure are illustrative of patches of different scattering strength within the resolution cell of the sonar. In this figure ϕ is the equivalent two-way horizontal beam width of a line array [9], H is the height of the transducer, and R is the slant range to the insonified area. The transducer height above the seafloor, H, was between 5 and 8 m for all measurements. The beam pattern of the sonar used in this study was rotationally symmetric with a beamwidth of 20°. From each experimental site, 200 $1ms$ pulses were transmitted at a rate of one per second and the returns were analyzed at each of four transducer tilt angles were analyzed. This arrangement along with the 20° vertical beamwidth of the transducer allowed measurements to be taken over a large range of grazing angles. Using the transducer calibration value (pressure to voltage transfer function), processing gain and system gains, the absolute received levels at the hydrophone were recovered from the recorded data. System gains were measured while at sea.

2.1 Scattering strength

In order to obtain quantitative seafloor information from the received level, three effects that modify the sound pressure level as the pulse travels from the source to the seafloor and back to the receiver have been taken into account. These three factors are the effects of the beam pattern (BP), transmission loss (TL), including both spherical spreading and absorption (α), and equivalent insonified area

$$A = \phi R \left(\sqrt{(R + c\tau/2)^2 - H^2} - \sqrt{R^2 - H^2} \right) \tag{1}$$

With the height of the transducer held constant, the insonified area (resolution cell) increases with range (or conversely decreases with grazing angle, θ) which will be seen to have a large effect on the scattering amplitude statistics. With the above described components, seafloor backscattering strength as a function of time can readily be calculated using an inverted form of the sonar equation with a knowledge of

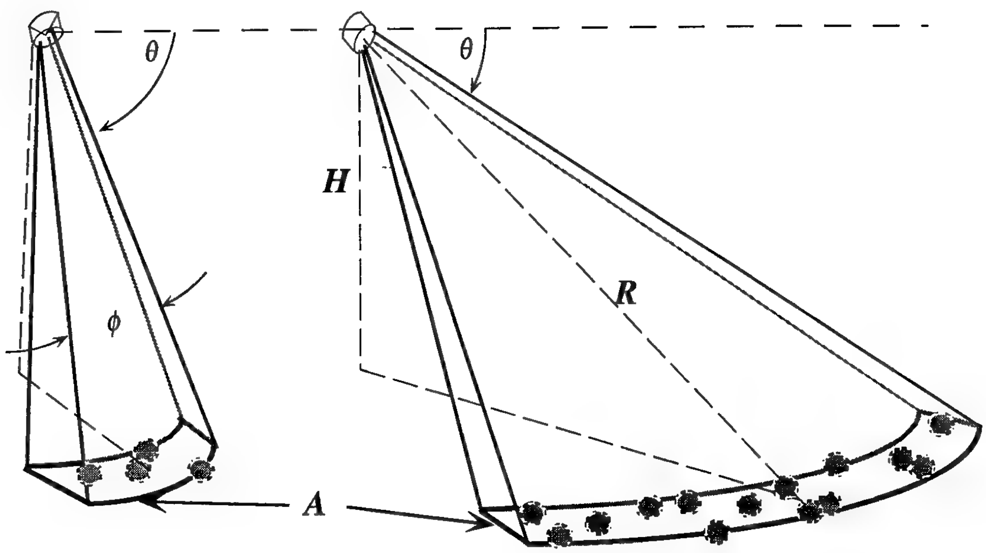

Figure 2 *Experimental configuration.*

the source level, transducer calibration and logging calibration. This is accomplished with the equation:

$$BSS = RL - SL - 2BP + 2\alpha R + 2TL - 10\log A \qquad (2)$$

where BSS is mean backscattering strength in dB/m^2, RL is the received level on the hydrophone in dB *re*:1 μPa and SL is the transducer on-axis source level in dB *re*:1 μPa at 1 m. The backscattering strength as a function of grazing angle can then be obtained from knowledge of the transducer height and the sound speed of the sea water. In data processing only grazing angles within the 3 dB down points of the one-way vertical beam pattern were considered (20° for the transducer used for this experiment). The 20° vertical beamwidth of the transducer allowed scattering strength measurements to be taken with four tilt angles over a large range of grazing angles (for most sites the range of grazing angles from which data were obtained was from 10° to 80°).

Backscattering strength resulting from the inversion described above from four sites is shown in the top graphs of Figs. 3 – 6. Because all system dependent factors, as well as measurement geometry effects (including spreading loss and absorption) and the insonified area contribution have been removed from the original raw data, the resulting inverted values represent the true quantitative acoustic response of the seafloor (backscattering strength.) Thus, in the graphs, quantitatively correct values indicate the different scattering properties of the three sites. The general patterns of the curves for the measurement sites are consistent with values reported near this frequency in that they approach a maximum as they near normal incidence, fall

off to a nearly constant level over a wide range of grazing angles, then decrease at low grazing angles. In some of our sites the reverberation to noise ratio is too low to give reliable scattering strength estimates at the smallest grazing angles as seen by Fig. 3 where the minimum grazing angle is 20°. The shellfish covered site had extremely high levels of backscatter at 80 kHz as did the posidonia covered site. Surprisingly the sand and mud sites shown in these examples had similar levels of backscattering, suggesting that absolute level is not sufficient to separate different bottom types. The next section will present a quantitative comparison between the different bottom types and their respective backscatter strength for different grazing regimes.

2.2 Amplitude statistics

Reverberation from mine hunting sonars typically exhibits a decay in the power level with range as the transmission loss increases. However, the statistical distribution of the reverberation may also vary. Statistical analysis of reverberation requires independent and identically distributed data. Independent data may be obtained within an individual ping by taking samples separated by the correlation width of the data. The received reverberation data were matched filtered using the transmitted waveform (1ms sinusoid at 80kHz, which has an effective bandwidth of 1kHz), basebanded to zero Hertz and decimated to a sampling frequency of 20 kHz. It was confirmed by correlation analysis that the decimation (which amounted to taking every 15th point) adequately decorrelated the data. The resulting data are statistically independent and indexed by grazing angle and ping number. To analyze the change in the statistical distribution of the reverberation and not the change in the power level, the data for each individual grazing angle are normalized by the power level as estimated from the ensemble of 200 pings.

Ideally, a statistical analysis would be performed for each grazing angle from 10°–80° as obtained from the four tilt angles (10°, 30°, 50°, and 70°). However, as an ensemble of only 200 pings is available and because it is expected that the reverberation statistics change slowly with grazing angle, grouping data across grazing angles is necessary and feasible. To avoid the issues of nonstationarity introduced by acquiring the data for different tilt angles at different times, the data from each tilt angle are grouped. To ensure that the grouped data are identically distributed (i.e., the normalized amplitude statistics are stationary), the Mann-Whitney test was applied as in Stanic and Kennedy [2, 3] across grazing angle and ping number. Data that failed the Mann-Whitney test with a 5% probability of Type I error (i.e., the probability that identically distributed data fails the Mann-Whitney test is 0.05) were excluded from the analysis.

Rayleigh, Weibull, K, and three-component Rayleigh mixture distributions were com-

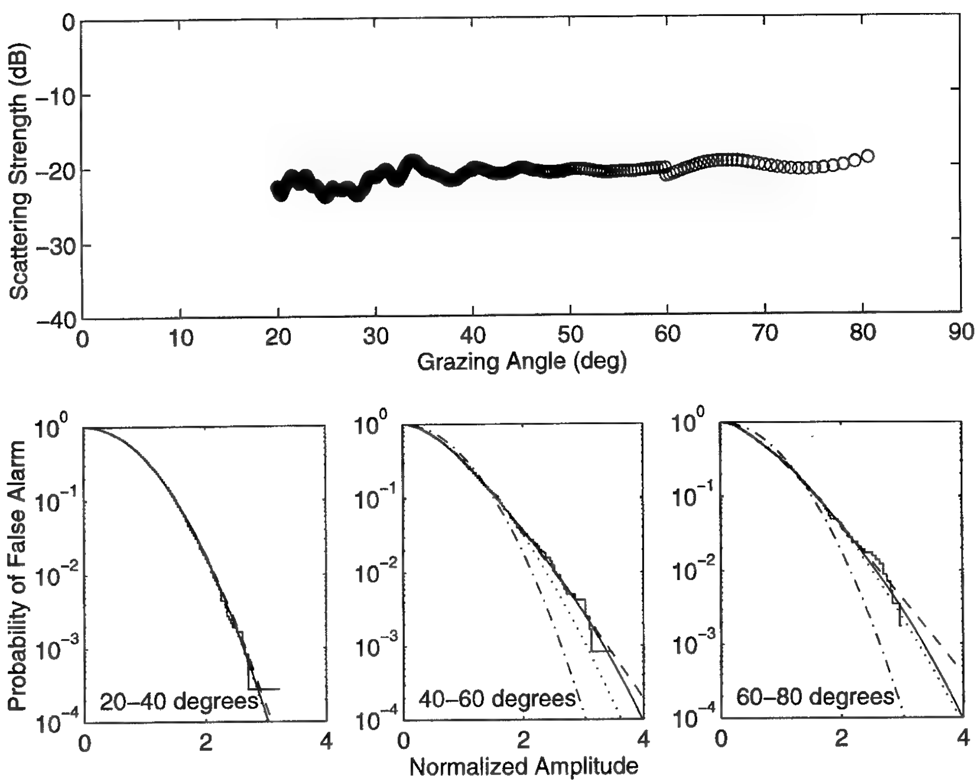

Figure 3 *Posidonia statistics - station RR06. The dashed-dotted line is the Rayleigh distribution, the dotted is the Weibull, the dashed is the K, and the solid is the Rayleigh mixture*

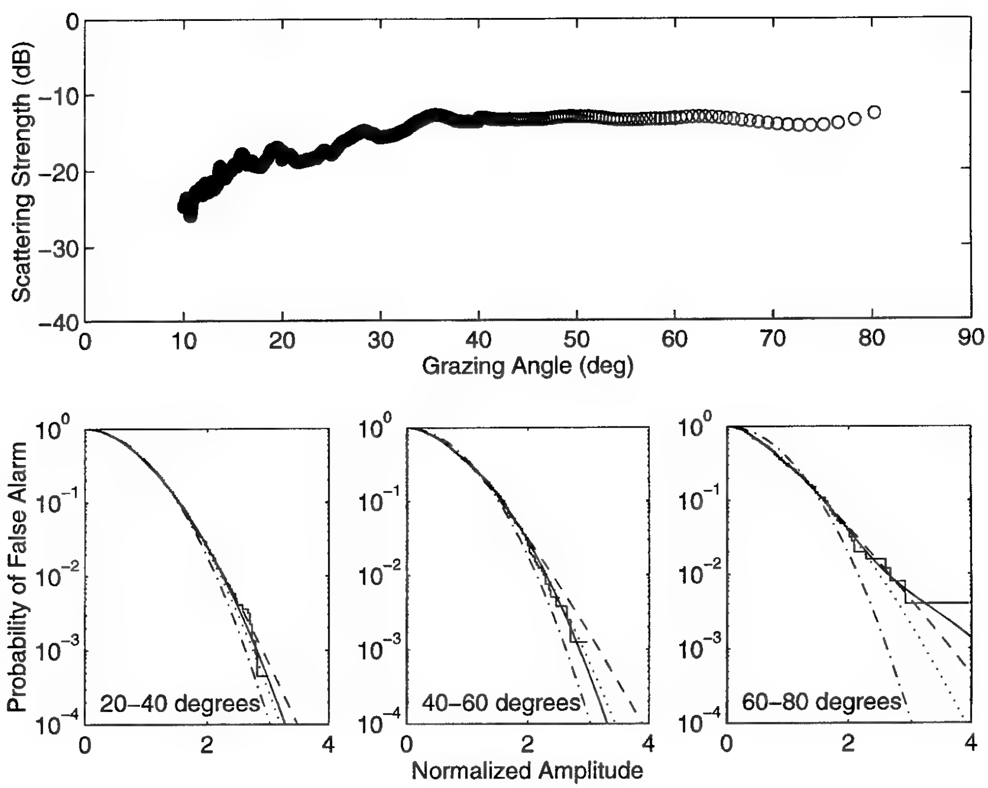

Figure 4 *Shellfish statistics - station RR13. Line types as in Fig. 3*

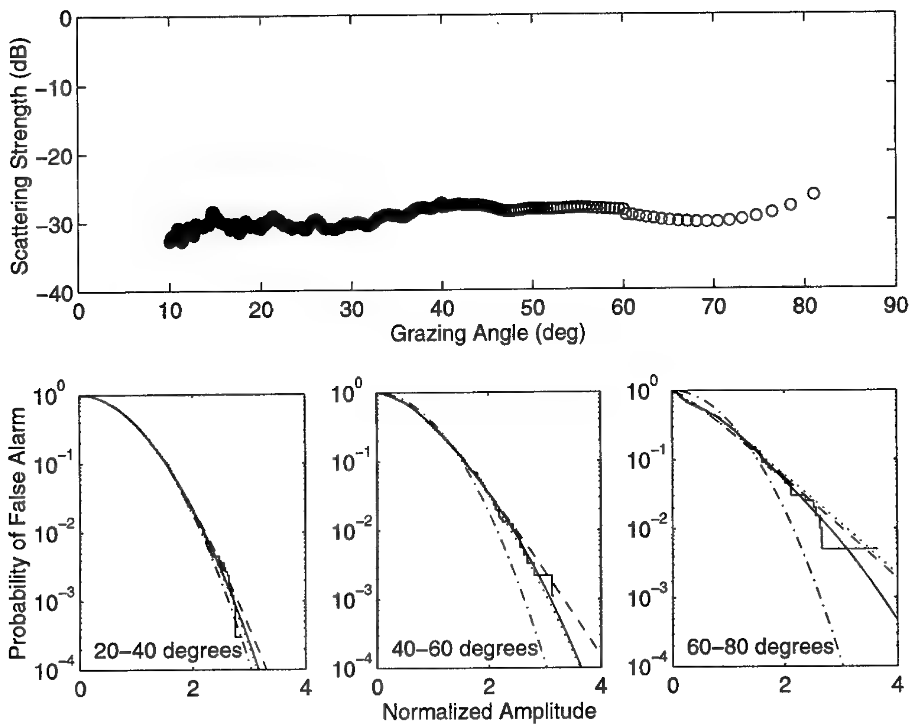

Figure 5 *Sand statistics - Station RR12. Line types as in Fig. 3*

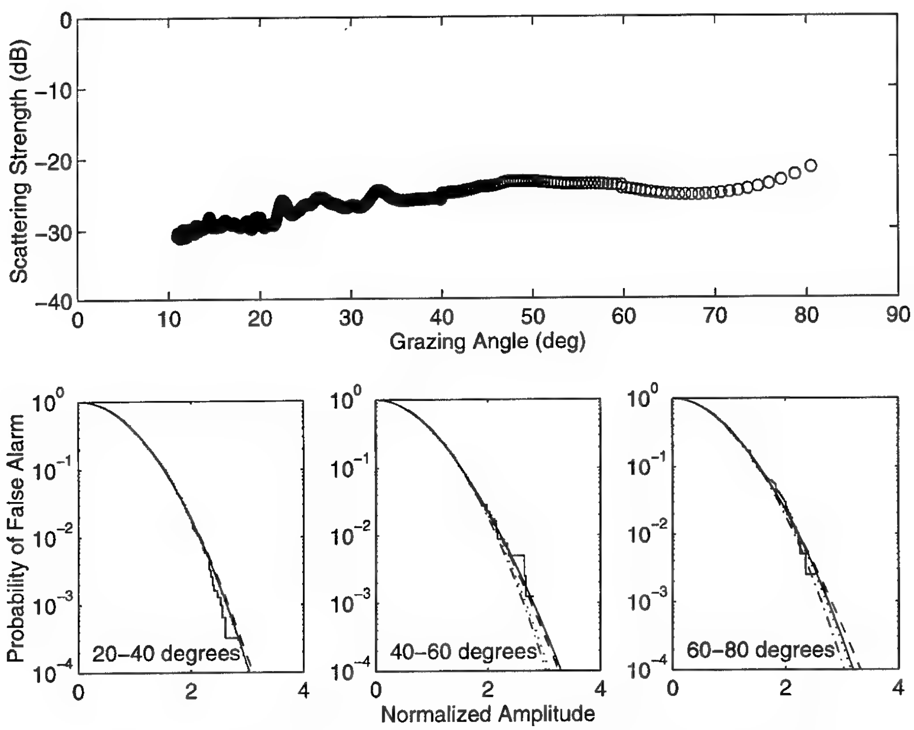

Figure 6 *Mud statistics - station RR09. Line types as in Fig. 3*

Table 1 *Distribution functions.*

Function	*PDF*	*CDF*
Rayleigh	$\frac{2x}{\lambda}e^{-\frac{x^2}{\lambda}}$	$1-e^{-\frac{x^2}{\lambda}}$
Weibull	$\alpha\beta x^{\beta-1}e^{-\alpha x^\beta}$	$1-e^{-\alpha x^\beta}$
K	$\frac{4}{\sqrt{\alpha}\Gamma(\nu)}\left(\frac{x}{\sqrt{\alpha}}\right)^\nu K_{\nu-1}\left(\frac{2x}{\sqrt{\alpha}}\right)$	$1-\frac{1}{\Gamma(\nu)2^{\nu-1}}\left(\frac{2x}{\sqrt{\alpha}}\right)^\nu K_\nu\left(\frac{2x}{\sqrt{\alpha}}\right)$
Rayleigh mixture	$\sum_{i=1}^m \epsilon_i \frac{2x}{\lambda_i}e^{-\frac{x^2}{\lambda_i}}$	$1-\sum_{i=1}^m \epsilon_i e^{-\frac{x^2}{\lambda_i}}$

pared to the experimental PDFs. The Weibull, K, and Rayleigh mixture distributions have the Rayleigh distribution as a submember. The Weibull distribution has traditionally been used to describe amplitude distributions and often does a better job than the Rayleigh. The K distribution, successfully used to describe the statistics of radar sea surface clutter [4, 5], is the product of two components: a rapidly fluctuating Rayleigh (or 'speckle') distributed component and a chi distributed component. The physical interpretation is that the Rayleigh distributed component is from many scatterers that are modulated by large scale (time varying) structure. The Rayleigh mixture model [8] is a combination of Rayleigh random variables with each component having its own power. This distribution can be thought of as describing scattering from two (or more) different types of materials in a manner similar to that put forward by Crowther [7]. The PDFs used in this report and their associated cumulative distribution functions are given in Table 1. Fitting the model distributions to the experimental results entailed estimating the parameters of each of the candidate cumulative distribution functions (CDFs). Details on the estimation of parameters for each of the distributions used in this analysis can be found in Abraham [10]. Maximum likelihood estimates obtained using an iterative algorithm [11] were used for the parameters of the Weibull distribution, method of moments estimates were used for the parameters of the K distribution, matching the mean and variance, and for the Rayleigh mixture model the maximum likelihood parameter estimates were obtained using the expectation-maximization (EM) algorithm [10].

In addition to the scattering strength curves, Figs. 3 - 6 also show graphical examples of the experimentally observed reverberation PDFs along with the fitted models. The non-Rayleigh nature of the reverberation distributions is readily seen in the high grazing angle shellfish, posidonia, and sand data. The distributions tend to Rayleigh at lower grazing angles. A simple explanation for this effect is that as a consequence of the height of the transducer remaining constant the resolution cell of the sonar will increase at the smaller grazing angles. More patches of seafloor are included in the

beam at low grazing angle which drives the amplitude distribution toward Rayleigh as the central limit becomes valid. Chotiros [1] has has observed similar effects of changes in the receiver horizontal beamwidth (resolution cell size) on reverberation statistics with the widebeam results tending toward Rayleigh. A quantitative table of goodness of fit of the observed data to each of the model distributions will be shown in the next section.

3 Statistical Results

To evaluate the flexibility and accuracy of the models in representing the reverberation from the different seafloor types, the Kolmogorov-Smirnoff (KS) test statistic p-values were used to compare real data to model distributions [12]. Even though Kolmogorov's theorem does not hold when parameters estimated from the data are used to form the theoretical CDF [12], the approximate p-value formed from the KS statistic should give a sufficient measure of the goodness of fit between the model distributions and the observed distributions [10]. An analytical CDF with a larger p-value will indicate a better fit. Results are presented for each of fourteen sites and are grouped in terms of grazing angle. Table 2 shows bottom type, average scattering level, and K-S p-values for the 60° to 80° grazing angle, Table 3 for 40° to 60° grazing angle, Table 4 for 20° to 40° grazing angle, and Table 5 for 10° to 20° grazing angle. Any p-values above 0.8 are shown in bold to highlight the best fits to observed data.

Quantitative agreement is seen with the qualitative assessment of the last section. The highest grazing angles (40°-80°) are usually not well described by the Rayleigh distribution. The insonified area at any given time at high grazing angles is small so that only a few patches of differing scattering strength are included in the beam. In this case the central limit becomes invalid resulting in non-Rayleigh reverberation. In most cases, the Weibull, Rayleigh mixture, and K distributions all match the observed distribution better than a standard Rayleigh. This results from the fact that the these higher order model distributions have more parameters to tweak (see Table 1) when trying to fit the distributions estimated from the observed data. The Rayleigh describes the amplitude distribution well at the lowest grazing angles but, as the other candidate PDFs contain the Rayleigh as a subset, they also perform adequately. The Rayleigh mixture and K distributional models are the most robust of the distributional models in fitting the observed data, working over the entire range of grazing angles (or resolution cell size).

Tables 2 – 5 also display the mean scattered level (averaged over the 20° grazing angle bin) for each station. Although the bottom types were not always separable using the mean scattering level, in general the muds displayed the lowest scattering levels, the sands gave medium levels, and the shellfish and posidonia covered bottoms showed the highest scattering levels. The many exceptions to this general rule on mean scattering strength suggests that scattering strength is not an accurate descriptor of sediment type. Any seafloor classification scheme based on mean scattering strength

should include other parameters affecting the scattered level such as the interface roughness spectrum or distributions of discrete scatterers on the seafloor.

Table 2 *Results for selected sites and for 60°-80° grazing angle.*

Station	*Bottom Type*	*Level*	*Rayleigh*	*Weibull*	*Mixture*	*K*
RR04	sand/shell	-19.2 dB	0.215	0.590	0.763	0.362
RR05	coarse sand	-23.1 dB	0.745	**0.998**	**0.980**	**0.980**
RR06	posidonia	-20.0 dB	1.04×10^{-9}	0.667	**0.983**	**0.933**
RR07	mud	-21.7 dB	0.161	0.667	**0.834**	**0.915**
RR08	mud	-19.4 dB	0.6309	0.758	**0.963**	**0.913**
RR09	mud	-23.5 dB	**0.902**	**0.986**	**0.998**	**0.999**
RR10	sand/shell	-20.4 dB	**0.818**	**0.843**	**0.818**	0.747
RR11	sand/shell	-23.0 dB	**0.992**	**0.999**	**0.997**	**0.999**
RR12	medium sand	-28.9 dB	3.42×10^{-12}	0.543	**0.977**	0.123
RR13	shells	-13.8 dB	1.57×10^{-4}	0.440	**0.850**	**0.802**
RR14	sand/shell	-23.2 dB	1.44×10^{-5}	0.090	**0.991**	0.098
RR15	sand/shell	-22.6 dB	7.95×10^{-13}	**0.891**	0.739	0.451
RR16	mud	-25.7 dB	0.026	0.473	**0.999**	**0.875**
RR17	mud	-22.1 dB	0.071	0.492	**0.865**	**0.816**

Table 3 *Results for selected sites and for 40°-60° grazing angle.*

Station	*Bottom Type*	*Level*	*Rayleigh*	*Weibull*	*Mixture*	*K*
RR04	sand/shell	-21.8 dB	0.659	**0.884**	**0.841**	**0.914**
RR05	coarse sand	-26.4 dB	**0.864**	**0.905**	**0.864**	0.797
RR06	posidonia	-21.0 dB	1.28×10^{-7}	0.367	**0.989**	**0.996**
RR07	mud	-21.9 dB	0.487	0.691	0.784	**0.874**
RR08	mud	-23.5 dB	0.762	**0.877**	**0.963**	**0.975**
RR09	mud	-23.8 dB	**0.827**	**0.979**	**0.999**	**0.999**
RR10	sand/shell	-21.2 dB	**0.978**	**0.853**	**0.978**	**0.984**
RR11	sand/shell	-24.4 dB	**0.953**	**0.941**	**0.953**	**0.969**
RR12	medium sand	-28.2 dB	4.25×10^{-4}	0.716	**0.881**	0.615
RR13	shells	-13.5 dB	0.002	0.508	**0.963**	**0.866**
RR14	sand/shell	-26.1 dB	1.36×10^{-7}	0.515	**0.968**	0.179
RR15	sand/shell	-22.6 dB	0.151	**0.967**	**0.988**	**0.880**
RR16	mud	-25.4 dB	0.246	0.785	**0.951**	**0.965**
RR17	mud	-24.6 dB	0.118	**0.947**	**0.878**	**0.931**

Table 4 *Results for selected sites and for* 20°-40° *grazing angle.*

Station	*Bottom Type*	*Level*	*Rayleigh*	*Weibull*	*Mixture*	*K*
RR04	sand/shell	-22.6 dB	**0.920**	**0.967**	**0.919**	**0.811**
RR05	coarse sand	-26.6 dB	0.112	0.799	**0.918**	**0.973**
RR06	posidonia	-21.8 dB	**0.955**	**0.982**	**0.955**	0.794
RR07	mud	-27.1 dB	0.746	**0.942**	**0.941**	**0.840**
RR08	mud	-27.0 dB	0.453	0.799	0.725	**0.878**
RR09	mud	-27.0 dB	**0.941**	**0.886**	**0.941**	**0.974**
RR10	sand/shell	-23.7 dB	**0.803**	**0.983**	**0.952**	**0.980**
RR11	sand/shell	-26.1 dB	**0.812**	**0.871**	**0.986**	**0.885**
RR12	medium sand	-29.5 dB	0.070	**0.927**	0.616	0.749
RR13	shells	-16.2 dB	0.014	0.328	**0.888**	**0.863**
RR14	sand/shell	-26.7 dB	0.005	0.699	0.746	0.637
RR15	sand/shell	-22.8 dB	0.022	**0.903**	**0.847**	**0.900**
RR16	mud	-26.2 dB	**0.888**	**0.924**	**0.888**	**0.877**
RR17	mud	-27.7 dB	0.288	**0.836**	**0.962**	**0.910**

Table 5 *Results for selected sites and for* 10°-20° *grazing angle.*

Station	*Bottom Type*	*Level*	*Rayleigh*	*Weibull*	*Mixture*	*K*
RR05	coarse sand	-28.9 dB	**0.922**	**0.871**	0.797	0.782
RR07	mud	-30.3 dB	**0.897**	**0.995**	**0.897**	0.744
RR08	mud	-28.4 dB	0.671	**0.958**	**0.909**	0.759
RR09	mud	-30.1 dB	**0.995**	**0.999**	**0.995**	**0.875**
RR10	sand/shell	-24.7 dB	**0.970**	**0.997**	**0.999**	**0.998**
RR12	medium sand	-29.0 dB	0.204	**0.915**	**0.902**	**0.912**
RR13	shells	-21.1 dB	**0.939**	**0.999**	**0.968**	**0.992**

4 Conclusions

The statistics of acoustic seafloor reverberation have been investigated for data taken at 80kHz from fourteen shallow water sites around Sardinia and Sicily. The bottom characteristics of many of the sites were frequently neither spatially nor temporally homogeneous.

Rayleigh PDFs do not accurately represent the statistical properties of the measure reverberation from the study sites, especially at high grazing angles. This result may be attributed to the number of patches of differing scatterer density or strength included in the sonar resolution cell at a given grazing angle. In general, for seafloor environments that are inhomogeneous (patchy), the smaller the resolution cell size the more non-Rayleigh the reverberation. This relationship will depend on the relative sizes of the patches and the insonified area. Rayleigh mixture or K distributions are the closest fit to the observed distributions over all bottom types at high grazing angles and, as these contain the Rayleigh distribution as a submember, they also perform well at low angles. A 3-component Rayleigh mixture model was used in this analysis but this could be expanded to include more components which would allow it to fit almost any distribution.

The mean scattering levels were not found to correlate well with bottom type.

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Title

Statistical evaluation of 80 kHz shallow-water seafloor reverberation

Abstract

Knowledge of the background reverberation environment is a prerequisite for the design of any target detection scheme. While the problem of understanding and predicting high-frequency background reverberation level or mean energy scattered per unit area of the sea bed has received considerable attention, studies of high frequency reverberation amplitude statistics are relatively scarce. Of these studies, many have dealt with scattering from quasi homogeneous seafloors in terms of bottom type whereas most shallow water areas will not be homogeneous but will have patchiness in space and time which will have a strong influence on reverberation amplitude statistics.

In this work a comparison is presented between 80 kHz reverberation statistics obtained at shallow water sites around Sardinia and Sicily. The data include measurements from several distinct bottom provinces, including sites populated with *Posidonia oceanica* or live Bivalvia. Results of the analysis are cast both in terms of mean power level or backscattering coefficient as well as of the amplitude statistics. The reverberation statistics did not always exhibit a Rayleigh probability distribution function (PDF), but exhibited statistical distributions with heavier tails. Several more appropriate models of reverberation PDF were examined in order to better describe the measured amplitude distributions. The Rayleigh mixture and the K models were found to be the most robust in describing the observed data.

Keywords

non-Rayleigh reverberation – seafloor scatter – high frequency – posidonia

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